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POWER BUDGET CONSIDERATIONS - LOS PATHS

The objective of this note is to put forth some basic radio link power budget considerations for line-of-sight (LOS) paths to emphasize required transmitter power with range for several frequency domains. The path model will be highly idealized in the sense that statistical signal distortions and variations in path loss due to terrain will not be treated. The impact of these factors will be the subject of a subsequent note.

A particular budget is constructed by totaling the "signal path" items and the "noise path" separately in terms of received power; the difference being the signal-to-noise ratio.

The power budget items in their most basic form can be listed as follows:

1.	Transmitter power (peak)	dBW
2.	Transmitter antenna gain	dB
3.	Transmission loss	(dB)
4.	Receive antenna gain	dB
5.	Signal power received (peak)	dBW subtotal
6.	Reference noise (kT_0/Hz)	(204) dBW @ 290°K
7.	Noise bandwidth	dB
8.	Receive system noise temperature ratio	dB
9.	Noise power received	dBW subtotal
10.	C/N (signal-to-noise ratio), (5) -(9)	dB

The signal powers are parenthetically shown at peak as a reminder that we are addressing the energy per bit as opposed to average transmitter power. The C/N is compared with E/No, the signal chip energy to noise ratio, for a particular modulation scheme (assuming 1 Chip/Hz) and a required BER and the transmitter power is adjusted to make the ratio of C/N to E/No unity

or better. In the paragraphs to follow, each pertinent element of the budget will be briefly discussed with values being assigned where appropriate and finally several typical budgets will be presented to bound the power, range, and frequency dependencies.

TRANSMISSION LOSS

Transmission occurs over a curved earth which, in general, is not locally smooth and often the path passes diffracting obstacles of substantial size. A generalization is difficult to make for arbitrary paths, but it must, even ideally, depart from free space transmission or, alternatively, transmission over a smooth flat earth. It will be convenient to discuss range in terms of the radio LOS distance which is given by

$$d = (2h)^{1/2}$$

Where d is the distance in miles
h is the antenna height (of one path end) in feet
(dimensionally correct with a constant of unity
having dimensions of miles as 4/3 earth radius
is roughly 5284 miles)

the formula assuming an effective 4/3 earth radius and moderate antenna heights.

The free space loss is given by the formula:

$$\frac{WR}{WT} = G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2$$

Where W_R, W_T are respective receive/transmit powers

G_R, G_T are respective receive/transmit gains

λ is wavelength in same dimensions as range, R

Okumura, et. al. show for the land mobile case and hub antenna heights in the 30-100 meter range that the loss falls off at about 40 dB/decade and keyed to about 40 dB excess loss below free space at the LOS range. A simple modification to the free space loss formula is then:

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$$\frac{W_R}{W_T} = G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2 \cdot \frac{1}{\left(1 + \frac{R}{k}\right)^2}$$

Where, for 40 dB at LOS range, gives

$$k = d/100 \text{ as } \left(1 + \frac{R}{k}\right)^2 \simeq \left(\frac{R}{k}\right)^2 = \left(\frac{d}{k}\right)^2 = 10{,}000$$

This behavior is in substantial agreement with CCIR report 370-1 at low antenna heights over land. The G_T, G_R are taken to be free space values and a nominal amount of terrain roughness is assumed; meaning largely that the ground reflected ray component of the secondary antenna pattern is, in effect, "scattered out of the aperture". The loss will be computed for 3, 10, and 30 miles at frequencies of 400, 1600, 6400, 25,600 MHz in data to follow later. Antenna heights of 30 and 100 meters at one end will be assumed talking to an antenna 3 meters high.

For reference, values of free space attentuation only (due to $\left(\frac{\lambda}{4\pi R}\right)^2$) is given in the table below.

Free Space Attenuation (dB)

	Frequency, MHz			
Range (mi.)	400	1600	6400	25,600
3	98.6	110.6	122.6	134.6
10	109.0	121.0	133.0	145.0
30	118.6	130.6	142.6	154.6

SYSTEM NOISE TEMPERATURE

System noise temperature, again in its simplest form, is given by:

$$T_s = \alpha T_A + T_0 (1 - \alpha) + T_1 + \sum_{m=2}^{M} \frac{T_m}{g_m - 1}$$

referred to the preamplifier input where:

α is the transmission line coefficient

T_A is the antenna temperature

T_1 is the preamplifier or "first stage" temperature

T_m, g_m are the temperatures and gains of succeeding stages.

This formulation neglects mismatch loss, directional couplers, non-reciprocal devices and, etc.

For simple omnidirectional antennas, it is doubtful that the antenna temperature will ever be less than $T_o/2$ (half the aperture looks at the galactic sky noise which in large scale approaches 0°Kelvin at SHF) for repeaters and T_o for greater than kT_o in rural-suburban areas. To further simplify this analysis, let us assume the "line loss" to be negligible, then the T_o is the sum of the antenna and receive temperatures. System temperatures for the fore-referenced frequency ranges will typically be as shown in the table below:

f(MHz)	T_A(°K)	T_R(°K)	T_S(°K)
400	1200	550 Transistor amp	1750
1600	500	550 Tunnel Diode amp	1050
6400	300	190 Uncooled paramp	490
25600	300	660 Uncooled paramp	960

ANTENNA GAIN

The antenna gain for small omnidirectional antennas (possibly hemispherical) will be 0-2 dB. We will use 2 dB in the computations. For repeaters and larger terminals the gain may be 4-8 dB. We will use 4 dB.

BANDWIDTHS

We will assume a bandwidth of 100 kHz for the computations.

E/No

This ratio will vary depending on whether or not the noise character is guassian or somewhat impulsive and also whether or not fading is assumed; and, of course, on the allowable BER. We will assume E/No of 13 dB and one chip/Hz of bandwidth.

POWER BUDGET CALCULATIONS

Power budgets were computed based on the above discussion and the results are given in the six tables to follow. Perhaps the most striking effect is that of using simple "constant gain" antennas over the frequency range. This "hurts" in terms of required transmitter power by 12 dB each time the frequency goes up by a factor of 4.

For the assumption made, the conclusions are as follows:

(1) ranges in excess of 10 miles are impractical for this type operation;

(2) for ranges as great as 10 miles, the probable frequency choice is somewhere between UHF and L band, i.e., 400 - 1600 MHz;

(3) tripling the antenna height results in a nominal 5.2 dB improvement in required transmitter power.

(4) If we wish to further consider the higher frequencies while maintaining simple antennas, reduction of the channel bandwidth certainly would help.

POWER BUDGET COMPUTATION

	3 mile range 30m height				3 mile range 100m height			
Frequency	400	1600	6400	25600	400	1600	6400	25600
1. Transmitter power	-14.4	-4.6	4.1	19.0	-19.6	-9.8	-1.1	13.8
2. Transmit antenna gain	2	2	2	2	2	2	2	2
3. Transmission Loss	-124.8	-136.8	-148.8	-160.8	-119.6	-131.6	-143.6	-155.6
4. Receive antenna gain	4	4	4	4	4	4	4	4
5. Signal power received	-133.2	-135.4	-138.7	-135.8	-133.2	-135.4	-138.7	-135.8
6. Reference noise (kT_o/Hz)	-204	-204	-204	-204	-204	-204	-204	-204
7. Noise Bandwidth	50	50	50	50	50	50	50	50
8. Receive system noise temperature ratio	7.8	5.6	2.3	5.2	7.8	5.6	2.3	5.2
9. Noise power received	-146.2	-148.4	-151.7	-148.8	-146.2	-148.4	-151.7	-148.8
10. C/N (signal-to-noise ratio), (5) - (9)	13	13	13	13	13	13	13	13
11. E/N_o	13	13	13	13	13	13	13	13

All numbers in db.

POWER BUDGET COMPUTATION

	10mile range 30m height				10 mile range 100m height			
Frequency	400	1600	6400	25600	400	1600	6400	25600
1. Transmitter power	6.4	16.2	24.9	39.8	1.2	11.0	19.7	34.6
2. transmit antenna gain	2	2	2	2	2	2	2	2
3. Transmission Loss	-145.6	-157.6	-169.6	-181.6	-140.4	-152.4	-164.4	-176.4
4. Receive antenna gain	4	4	4	4	4	4	4	4
5. Signal power received	-133.2	-135.4	-138.7	-135.8	-133.2	-135.4	-138.7	-135.8
6. Reference noise (kT_o/Hz)	-204	-204	-204	-204	-204	-204	-204	-204
7. Noise Bandwidth	50	50	50	50	50	50	50	50
8. Receive system noise temperature ratio	7.8	5.6	2.3	5.2	7.8	5.6	2.3	5.2
9. Noise power received	-146.2	-148.4	-151.7	-148.8	-146.2	-148.4	-151.7	-148.8
10. C/N (signal-to-noise ratio), (5) - (9)	13	13	13	13	13	13	13	13
11. E/N_o	13	13	13	13	13	13	13	13

All numbers in db

POWER BUDGET COMPUTATION

	30 mile range 30m height				30 mile range 100m height			
Frequency	400	1600	6400	25600	400	1600	6400	25600
1. Transmitter power	25.6	35.4	44.1	59.0	20.4	30.2	38.9	53.8
2. Transmit antenna gain	2	2	2	2	2	2	2	2
3. Transmission Loss	-164.8	-176.8	-188.8	-200.8	-159.6	-171.6	-183.6	-195.6
4. Receive antenna gain	4	4	4	4	4	4	4	4
5. Signal power received	-133.2	-135.4	-138.7	-135.8	-133.2	-135.4	-138.7	-135.8
6. Reference noise (kT_o/Hz)	-204	-204	-204	-204	-204	-204	-204	-204
7. Noise Bandwidth	50	50	50	50	50	50	50	50
8. Receive system noise temperature ratio	7.8	5.6	2.3	5.2	7.8	5.6	2.3	5.2
9. Noise power received	-146.2	-148.4	-151.7	-148.8	-146.2	-148.4	-151.7	-148.8
10. C/N (signal-to-noise ratio), (5) - (9)	13	13	13	13	13	13	13	13
11. E/N_o	13	13	13	13	13	13	13	13

All numbers in db

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